

THE MOONS OF JUPITER

PURPOSE:

To analyze the orbital motion of Jupiter's moons, and, using principles and equations learned in class, determine the mass of the planet. A second purpose is to allow you to work like an actual scientist, giving you the experience and fun of planning and carrying out a scientific investigation where you are *not* given a list of instructions, and where finding "the answer at the back of the book" is not the goal. The approach you develop and use is entirely up to you and your team. However, you are encouraged to borrow useful ideas from Newton, Kepler, Galileo, etc. (Astronomers do that as well, of course.)

You should develop your approach, and clear it with your TA, before starting to make observations and take data. The process of planning, conducting, and reporting your investigation is expected to take 2-3 weeks.

Equipment:

Scientific pocket calculator, Macintosh Computer, graph paper, and computer program The Galilean Satellites, (Modified by D. Duncan of the Univ. of Chicago), which allows you to observe Jupiter and four of its moons.

REQUIREMENTS:

This lab is to be done in groups. One student is to manipulate the computer, and the other is to take the data. If there are other student(s), they should watch and help by checking. This means **you**! It is **easy** to make mistakes in measurement, plotting, or calculation, so real scientists check their work and each other. You should also switch off from time to time so everyone gets a chance to use the computer. Each group of students may have different data. The computer simulation is based on the actual orbital data for each satellite. As a matter of fact, if you were to set the simulation for today's date and time, you could verify the position of the Jovian moons by direct observation through the telescope at the observatory.

INTRODUCTION AND HISTORICAL BACKGROUND

This lab can in principle be done by anyone with a small telescope, and we will actually observe Jupiter from the roof of Kersten. However, since the weather in Chicago is not entirely dependable, the computer simulation The Galilean Satellites replaces actual observing sessions at the observatory using the telescope. You will note that the computer also provides you some of the pitfalls of actual live telescopic observations, such as nights on which clouds prevent your taking data.

In 1609, Galileo Galilei heard of the invention of a new optical instrument by a Dutch spectacle maker, Hans Lippershey. By using two lenses, one convex and one concave, Lippershey found that distant objects could be made to look nearer. This instrument was called a telescope. Without even having seen an assembled telescope, Galileo was able to construct his own telescope with a magnification of about three. He soon perfected the construction of the telescope, and became famous as the builder of the world's best telescopes. His best telescopes had a magnification of about thirty.

Galileo immediately began observing celestial objects with his crude instrument. He was a careful observer, and soon published a small book of his remarkable discoveries called the "Sidereal Messenger". One can imagine the excitement these new discoveries caused in the scientific community. Suddenly, a whole new world was opened! Galileo found sunspots on the Sun, and craters on the Moon. He found that Venus had phases, much as the Moon has phases. He was able to tell that the Milky Way was a myriad of individual stars. He could see that there was something strange about Saturn, but his small telescope was not able to resolve its rings.

One of the most important discoveries was that Jupiter had four moons revolving around it. Galileo made such exhaustive studies of these moons that they have come to be known as the Galilean satellites. This "miniature solar system" was clear evidence that the theory of Ptolemy, which supposed that all celestial bodies revolved around the earth and which had been believed for many centuries, was false.

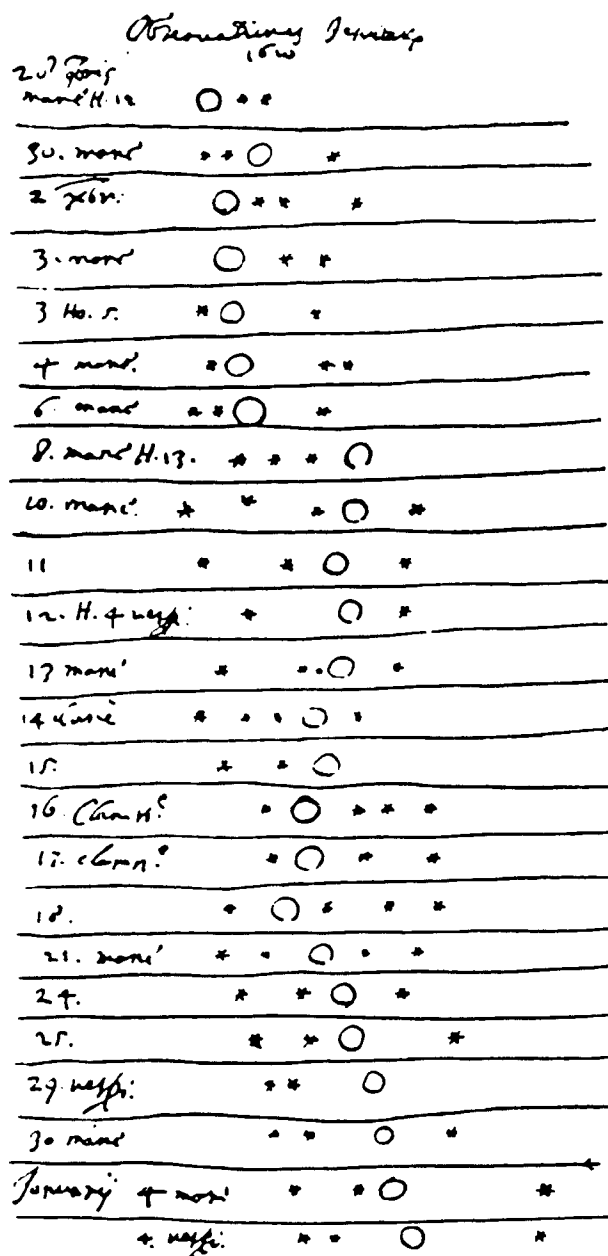
Because he was developing a world view which was not easily reconciled with the religious dogma of his period, Galileo was compelled to neither "hold nor defend" the Copernican hypothesis. Nevertheless, in 1632 he published his Dialogue on the Great World System which was a thinly disguised defense of the Copernican system. This led to his forced denunciation of the theory and confinement to his home for the rest of his life.

In this lab, you are going to repeat Galileo's observations (without threat of government condemnation). Today, we know some additional information which may be useful to you. The diameter of Jupiter is about 11.2 times the diameter of the earth, or 1.43×10^5 km, ~~or 5.20 a.u. (astronomical units).~~

The Galilean satellites are named Io, Europa, Ganymede and Callisto, in order of distance from Jupiter. You can remember the order by the mnemonic "I Eat Green Carrots". We also refer to them in this exercise as I, II, III and IV. If you looked through any small telescope, the picture might look like this:



In fact, here are some of Galileo's sketches (made on different nights):



On the computer screen, Jupiter and its moons will look much like Galileo's drawings. West is to the right and east is to the left. This is the way the sky looks through a telescope. You will very likely want to record the distance of a moon from Jupiter. Lucky for you, the measurement mode of the computer equipment you will use provides a direct readout in units of Jupiter's diameter, if you simply point the cross-hair at the moon and push the mouse button. The simulation is set to present data on the moons as they would be seen every 12 hours, as if you stayed up all night and made such observations in the winter when the nights are long. (The computer simulation improves on real life here.)

Operating the Computer Program

First let's take a look at the computer program to see what it shows. This is **not** to start doing the lab, just to familiarize you with the program. The section "PROCEDURE" below discusses actually doing the lab.

Start up your computer if it is not already on (see your lab instructor if necessary). Position the mouse cursor over the icon called "Jupiter Lab" and double click the mouse button. Wait for a yellow introductory screen and a pretty picture of Jupiter to be shown.

The Galilean Satellites program simulates the operation of an automatically controlled telescope with a charge coupled device (CCD) camera that provides a video image to a computer screen. It has a sophisticated computer program that allows convenient measurements to be made at the computer console and you can adjust the telescope's magnification as well. The computer simulation is realistic in all important ways, and using it will give you a good feel for how astronomers collect data and control their telescopes.

Entering Student Accounting Information


The program starts with a STUDENT ACCOUNTING screen. Enter your name, and those of your lab partners. Do not use punctuation marks. Press return after each name, or to skip to the next entry. Don't worry about entering the Table Number. Once you have moved to the next entry, you cannot change your response unless you rerun the program again. When all the information had been entered to your satisfaction, click OK to continue.

Startup Screen

A set of startup values is needed by the computer to establish your initial observation session. Most data is entered by positioning the cursor (by moving the mouse around) over the item you wish to select, and pushing the button on the mouse. This is called "clicking". Tell the program you wish to observe every 12 hours. The starting date is up to you. Don't be too afraid of making a mistake, especially if you keep good records. If you start over and set the computer program to the same date it will give exactly the same results.

After you have entered this information into the computer, it will display a screen similar to (BUT NOT EXACTLY LIKE) the following:

Galilean Satellites (C.7)	
SATELLITE ORDER	GIJCE
LOCAL DATE:	4 / 15 / 1992
LOCAL TIME:	14.2 HRS
UTC DATE:	4 / 15
UTC TIME	19 2 HRS



MAGNIFICATION: 300x

next observation

100X

200X

300X

QUIT

help

THE MAIN TELESCOPE SCREEN

You control the observing session from this screen. Jupiter is displayed in the center of your computer screen. To either side are the small point-like Galilean satellites. Even at high magnifications, they are very small compared to Jupiter. The current telescope magnification is shown at the bottom center. Click on the buttons which change the magnification. Notice how you "zoom" in and out. Click the button marked NEXT, and time will advance, and the moons move as they would in real life. You will have to keep track of the moons to determine which is which! After a few observations it should become clear which moon has the smallest orbit, which the largest, and so on. The orbits of Jupiters moons are nearly circular. Do they look like circles? Why do you think that is?! You may want to discuss how that affects the method you write out below.

If you point the "cross-hairs" at any one of the moons, it calculates the moon's distance from Jupiter in units of "pixels" and in units of Jupiter's diameter. Position the cursor on a moon, and hold down the mouse button. The measurement system displays how far the moon is away from the center of Jupiter (in both the X or left-right direction, and R, the radial direction. Since the moons are moving mostly left and right, "X" and "R" should be nearly the same). To measure a moon, identify it and measure its position. You can increase the magnification of the telescope; the highest magnification may give you better

accuracy. But you will have to decrease the magnification again to not lose track of which moon is which!

Universal time (the time in Greenwich, England) is displayed as well as dates. J.D. stands for "Julian Date." JD is simply a consecutive running number which was started a long time ago and which increases by one each day. If you measure elapsed time in Julian Days, you never have to remember which months have 30 days, which have 31, etc. Astronomers think it is easier to plot or subtract 2 Julian Days than, say, subtract Aug. 30 from Oct. 4. So if you plot how something changes with time, you might want to use "JD" as your x-axis.

From the main menu (called "File" at the very top of the screen) you can click on a help screen, RESTART, or QUIT the program altogether. You cannot continue where you left off if you QUIT the program. Restart allows you to restart at any date you set. You might need to restart if it takes you a while to determine which moon is which, or if you miss some observations for some reason. On the other hand, you could just keep observing for a few more days. You won't even get cold or tired, sometimes a hazard when you are at a real telescope....

Sometimes a moon is behind Jupiter, so it can't be seen at all!

PROCEDURE

It is now up to your team to assess the best way to measure the mass of Jupiter using information you can gain from studying the motions of the Galilean satellites.

Decide on what equation(s) you need to understand, and what you need to measure in order to determine Jupiter's mass. Start a **Lab Report** on a blank piece of paper and label the first section, "Procedure." **Put your name** on your report! Write a short description of what you plan to do, and show it to your TA. One issue you should address is the units you plan to use. At least at the end of your investigation, we want you to tell us your result for the mass of Jupiter compared to the earth's mass, (i.e. in units of "earth mass.") We also want you to estimate how accurate you think your result is. How did you decide how accurate you are? What are the main sources of error?

Leading Questions

Since we are nice and friendly professors and TA's, here are a few questions which may help you. Before you go and do all the work to measure the mass of Jupiter, you should have an idea of what sort of answer is reasonable, and what is not. (Answer these questions in your **Lab Report**.) The diameter of Jupiter is 11.2 times the diameter of earth. How does the volume of Jupiter compare to that of earth? If Jupiter was the same density as the earth, how would the masses compare?

(At the end of your investigation). From the mass that you found in your investigation, what can you conclude about the density of Jupiter? Does that give you any clues as to what it is or isn't made of?